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## Description

METHOD FOR THE PRODUCTION OF A BIPOLAR TRANSISTOR  
COMPRISING AN IMPROVED BASE TERMINAL

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The invention relates to a method for the production of a bipolar transistor comprising an emitter, a collector and comprising a base layer divided into an intrinsic base and an extrinsic base, and to a method for the production of the transistor.

The document "SiGe Bipolar Technology for Mixed Digital and Analog RF Applications", J. Böck et al. IEEE 2000 discloses transistors of the type mentioned in the introduction in which the base layer has an intrinsic section and an extrinsic section, the extrinsic section connecting a base contact to the intrinsic section. In this case, the extrinsic section has a relatively low boron doping. This results in the disadvantage of a high resistance of the base layer and leads to a reduction of the power gain even at relatively low frequencies and thus to an effective slowing down of the transistor. In addition, the higher base lead resistance brings about higher noise.

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US 6028345 B1 discloses a method for the production of a transistor comprising an extrinsic base doped in low-resistance fashion, in which a glass layer is deposited in highly doped fashion in the region of the extrinsic base, dopant being driven into the extrinsic base from said glass layer in a thermal step. This method has the disadvantage that the deposition of a sufficiently highly doped layer in a CVD process poses problems.

35 Therefore, it is an object of the present invention to specify a method of the type mentioned in the introduction by means of which a low-resistance base

terminal can be produced in a simple manner and which can be carried out simply and in controlled fashion.

5 This object is achieved according to the invention by means of a method according to claim 1. Advantageous configurations of the invention can be gathered from further claims.

10 The invention likewise utilizes the principle of a differential base, firstly a customarily weakly doped, crystalline semiconductor layer being provided as base layer. A region of said base layer which is provided for the later extrinsic base is doped more highly by  
15 indiffusion of a dopant of the first conductivity type from a dielectric layer deposited thereabove, so that a low-resistance base terminal can be realized therefrom. The low resistance of the base terminal or of the extrinsic base enables a transistor having only short switching times or having a high maximum switching  
20 frequency. Since the intrinsic base has a lower doping than the extrinsic base, the disadvantages associated with a high doping are avoided. In particular, the tunneling current between a later highly doped emitter and the (here not) highly doped intrinsic base is  
25 thereby suppressed.

According to the invention, however, the dielectric layer is not doped until after the deposition. This makes it possible to introduce a high dopant dose into  
30 the dielectric layer, and the thickness of said layer can be kept small. From a thin dopant-containing layer, in turn, the dopant can be outdiffused into the base layer in a much more controlled manner than from a thicker layer. In the case of the latter, the  
35 boundaries of the doping zone thus produced in the base layer would be more diffuse and the extent of the doping zone would be more difficult to control.

Compared with known methods for the implantation of dopant directly into the base layer, diffusion from the dopant-containing dielectric layer has the advantage that in this case no implantation-dictated defects and  
5 impurities arise in the base layer which could promote diffusion over and above the desired amount and would thus yield results difficult to reproduce.

The transistor produced according to the invention is  
10 preferably formed as an npn bipolar transistor. This means that the base layer just like the dielectric layer is p-doped, or that the dopant of the first conductivity type may produce a p-type doping, whereas the dopant of the second conductivity type may produce  
15 an n-type doping.

However, it is also possible to form the transistor according to the invention as a pnp bipolar transistor.

20 An oxide layer is preferably deposited as a dielectric layer over the base layer, for example in a CVD method. This layer has the advantage that a sufficiently high dopant dose can be introduced and that its dielectric properties are maintained even when there is a high  
25 content of dopant.

BF<sub>2</sub> is preferably introduced as the dopant. BF<sub>2</sub> has the advantage that its penetration depth can be controlled well during introduction by means of implantation into  
30 the dielectric layer.

The introduction of the dopant, and in particular the introduction of BF<sub>2</sub> into the dielectric layer is effected over the whole area or with the aid of an  
35 implantation mask which covers the area regions of the dielectric layer from which no dopant is to be diffused into the underlying base layer. In particular, the implantation mask has an opening in the region of the

extrinsic base, while it covers the region of the intrinsic base, so that no (additional) dopant can be introduced there. In the case of whole-area introduction of dopant into a dielectric layer applied  
5 over a large area, a patterning is subsequently effected, the base layer being uncovered for the emitter in a window.

The implantation mask may be applied on a continuous  
10 dielectric layer. Preferably, at least one emitter window that defines the later emitter/base contact is opened beforehand in the dielectric layer. The emitter is produced directly afterward by depositing an emitter layer over the whole area and patterning it in order  
15 not to damage the semiconductor substrate of the base that is uncovered in the emitter window during the implantation.

For the emitter layer, a semiconductor layer is  
20 applied, in particular a polycrystalline, amorphous or monocrystalline layer, which is doped with a dopant of the second conductivity type. However, it is also possible to permit the emitter layer to grow epitaxially. The emitter layer is subsequently  
25 patterned.

The implantation mask may then be produced over the emitter layer or the patterned emitter and comprises for example a photoresist layer and, if appropriate,  
30 further layers arranged below the latter, for example oxide and/or nitride layers. For patterning the emitter, use is preferably made of a photoresist layer which initially remains on the emitter and can later be used as an implantation mask for the doping of the  
35 dielectric layer.

The starting point for the production of the semiconductor substrate is preferably a semiconductor

wafer, for example a silicon wafer having weak doping of the first conductivity type. The collector is produced therein, for example by additional implantation of dopants for producing a heavily doped collector zone of the second conductivity type. However, it is possible, for the collector as well, to permit a semiconductor layer to grow epitaxially on the semiconductor wafer. Said layer can be doped in situ in the course of growth. However, it is also possible for such an epitaxial layer to be doped subsequently. Prior to the epitaxy, a buried layer is produced for the deeply situated collector connection zone. Well-type zones - wells - are subsequently produced by doping and subsequent diffusion and activation.

In the next step, the active transistor regions may be defined by isolating individual transistor regions from one another by means of oxide regions. Oxidic barrier layers, for example grown field oxide (LOCOS) or oxide-filled isolating trenches (STI = shallow trench isolation), are produced around the active transistor area. The oxide regions may also insulate the transistor regions from other regions on the surface of the semiconductor substrate. The active transistor region surrounded e.g. annularly by the insulating oxide regions has a diameter of e.g. 150 to 400 Å, remains free of oxide and forms the collector surface.

A semiconductor weakly doped with a dopant of the first conductivity type is subsequently deposited as a base layer over the semiconductor wafer with the defined transistor regions. The growth or deposition is effected under epitaxial conditions, the base layer likewise growing in monocrystalline fashion directly over a crystalline substrate material, while it grows in polycrystalline or amorphous form over the oxide regions or other noncrystalline regions. In this case, it is possible, prior to the epitaxy, to apply and

- pattern further dielectric intermediate layers between the semiconductor wafer and the epitaxial base layer. Said intermediate layers may serve for additional electrical insulation of the base layer from the semiconductor wafer. The intermediate layer or intermediate layers is or are then patterned such that a corresponding opening is provided at least in the active transistor region.
- 10 The base layer is preferably deposited with a layer thickness of e.g. 1000 to 2000 angstroms. The thickness of the electrically active base in the later bipolar transistor is significantly smaller, however, and amounts e.g. to only a fifth to a third of the original
- 15 thickness of the base layer. If the later base/emitter junction is not produced at the interface of the base layer, but rather is shifted deeper into the base layer, then this is taken into account in the thickness of the base layer during deposition by means of a
- 20 corresponding layer thickness reserve.

As just explained, the epitaxially grown base layer advantageously constitutes the topmost semiconductor layer of the semiconductor substrate, to which the dielectric layer is then applied directly, preferably in undoped fashion. However, it is also possible to produce a doping profile of boron, for example, in the base layer as early as in the course of growth. However, the base may also be defined without epitaxy

25 by means of corresponding doping directly in the surface of a semiconductor wafer.

Relative to the thickness of the base layer, the overlying dielectric has only a small layer thickness.

35 This is possible since the introduction of the dopant into the dielectric layer can be effected in a controlled manner such that the dopant is only introduced down to a specific maximum depth

corresponding to the thickness of the dielectric layer. This is achieved particularly when  $\text{BF}_2$  is used as the dopant. In addition, it is possible to incorporate in or introduce into the dielectric layer a high dose of  
5 dopant which is sufficient for a high doping of the underlying base layer. This dopant repository within the dielectric layer is then situated exclusively in area regions over the later extrinsic base.

10 In a controlled thermal step, the dopant is subsequently indiffused into the base layer. By controlling the layer thickness of the dielectric layer and the amount of dopant therein it is possible to conduct the diffusion such that the dopant indiffuses  
15 into the base layer from the dielectric layer down to a desired depth. It is thereby possible to minimize an undesirable lateral diffusion of the dopant within the base layer, so that the dopant distribution originally predefined by the implantation mask can also be  
20 transferred to the base layer and thus leads to a desired patterning of the transistor. After the outdiffusion of the dopant from the dielectric layer or the indiffusion into the surface of the semiconductor substrate, and in particular into the base layer, the  
25 dielectric layer can be removed, for example by etching.

However, it is also possible to leave the dielectric layer on the extrinsic base and, in a later step, only  
30 to open a window for the base contact in the dielectric layer, by means of which the extrinsic base and hence also the active base can be connected.

The transistor may be formed from a uniform  
35 semiconductor material, for example from silicon. However, it may also be formed as a heterojunction bipolar transistor in which at least one of the layers, selected from emitter, base and collector, contains

proportions of a further semiconductor, for example up to 40 atomic % of germanium. This proportion of germanium may be contained homogenously in the corresponding transistor layer or the corresponding transistor layer region. However, it is also possible to continuously vary the germanium content in a transistor layer and to permit it to rise for example in the direction of a pn junction. Since germanium has a different bandgap than silicon, the semiconducting properties, in particular the local bandgap, can thus be set to the desired value by way of the germanium content or by way of the content of a different or a further semiconductor. While the collector and base are preferably formed in monocrystalline fashion, the emitter may also be polycrystalline or amorphous. However, it is possible also to permit the emitter to grow epitaxially.

Individual or a plurality of transistor layers and, if appropriate, the layer provided with germanium may have, besides the dopant and the second semiconductor possibly present, even further dopings that determine the properties of the semiconductor. Thus, individual or a plurality of the transistor layers may have a defined content of carbon and/or nitrogen.

The invention is explained in more detail below on the basis of an exemplary embodiment and associated schematic figures. The figures serve for better illustration of the invention and are therefore depicted only schematically and in particular not in a manner true to scale.

Figures 1 to 6 show different method stages in the production of the bipolar transistor according to the invention on the basis of schematic cross sections through the wafer and the construction applied thereto.



Figure 7 shows a finished bipolar transistor in schematic cross section.

Proceeding from a semiconductor wafer HLW, for example  
5 a p-doped silicon wafer, firstly a buried layer is produced for the deeply situated collector connection by implantation of a substance that produces an n-type conductivity, for example phosphorus, and subsequent epitaxial growth of the collector zone K. This is  
10 followed by the production and activation of a doping for the wells. The active transistor regions TB are then produced. This is preferably effected by local oxidation and growth of field oxide. The individual transistors on the large-area semiconductor wafer HLW  
15 are then insulated from one another by the corresponding oxide regions OB. With the aid of the oxide regions, the transistors can also be insulated from other structures and circuit elements that are additionally integrated on the semiconductor wafer.

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Figure 1 shows the arrangement after the definition of the transistor regions. At this stage a conductive connection to the collector connection zone can also be created outside the active transistor zone by means of  
25 a doping referred to as a sinker.

A base layer BS is subsequently grown under epitaxial conditions directly over the active transistor regions TB and the oxide regions OB adjacent thereto. For this  
30 purpose, use is preferably made of a low temperature PE-CVD (plasma enhanced CVD) method or an LP-CVD (low pressure CVD) method in which the base layer can grow in monocrystalline modification at least in the region over the crystalline substrate, that is to say in the  
35 region of the intrinsic base. In this case, the base layer is lightly p-doped in situ, preferably with a given dopant content that varies over the layer

thickness, for example by direct incorporation of boron during growth.

Figure 2 shows a variant of the method in which at least one electrically insulating intermediate layer ZS is additionally applied over the semiconductor wafer prior to the growth of the base layer BS. The said intermediate layer is patterned in such a way that at least the transistor region TB remains uncovered. On account of the varying crystal modification and the intermediate layer possibly present, corresponding steps can form in the base layer. Figure 2 shows the arrangement after this method step.

A dielectric layer DS is subsequently deposited directly onto the base layer BS, for example an oxide layer in a CVD method (see figure 3).

In accordance with one variant, the dielectric layer DS is subsequent patterned and an emitter window EF is opened in the process. Over that an emitter layer heavily doped with a dopant of the second conductivity type, and in particular with arsenic, is then applied over the whole area. Preferably, a further layer of a dielectric, and in particular an oxide layer, is produced over that and the emitter layer is subsequently patterned with the aid of a photoresist mask, the desired emitter E remaining. However, the latter is not identical with the later electrically active emitter located in the crystalline zone of the base layer after diffusion. Figure 4 shows the arrangement after this method stage.

The next step involves introducing dopant into the dielectric layer DS with the aid of an implantation mask (not illustrated in the figure). The photoresist mask which remained above the emitter and with the aid of which the emitter E has already been patterned is

preferably used for this purpose. The method thus becomes self-aligning relative to the structure of the emitter. Otherwise, an implantation mask is used or produced which has openings at the locations into which  
5 the dopant is subsequently to be introduced.

The introduction of dopant into the dielectric layer DS is preferably effected by implantation, and in particular by implantation of  $\text{BF}_2$ . This is indicated by  
10 the arrows I in figure 5. The implantation conditions are chosen such that the maximum implantation depth of the dopant is under no circumstances greater than the layer thickness of the dielectric layer. This prevents imperfections from arising in the base layer BS.

15 In the next step, the dopant is transferred from the dielectric layer DS into the base layer BS by setting the desired diffusion conditions. The outdiffusion of boron from the dielectric layer DS into the underlying  
20 section of the base layer BS is effected at normal pressure under inert conditions, for example in an RTP (rapid thermal processing) installation at a temperature of  $960 - 1020^\circ\text{C}$  for a duration of 5 - 30s. In this way, a highly doped extrinsic base is obtained,  
25 while the intrinsic base retains its original doping.

At the same time as the diffusion of the boron from the dielectric layer, dopants of the second conductivity type also diffuse from the emitter into the base layer  
30 BS. The emitter is preferably n-doped with arsenic, which is distinguished by a lower diffusion rate compared with the more mobile boron. It is thereby possible for the boron to be permitted to indiffuse down to a greater depth corresponding e.g. to the layer  
35 thickness of the base layer BS. By contrast, arsenic is indiffused to only a smaller maximum depth, which is indicated by a dotted line in figure 6. In this case, the semiconductor junction between the p-conducting

base layer and the n-doped emitter is simultaneously also shifted into the monocrystalline base layer BS as far as said line. What is thereby achieved is that the emitter/base junction is remote from the imperfections existing at layer boundaries of base layer/emitter layer.

As a result of the entire diffusion operation, the base layer is highly doped and thus acquires low resistance in the region of the extrinsic base EB. The intrinsic base IB, which provides the actual base function in the bipolar transistor, is left in the remaining predominantly monocrystalline region of the base layer BS. The intrinsic (active) base IB is electrically connected via the extrinsic base EB, which, as a result of the high doping, ensures a high conductivity and thus a low-resistance base terminal. Between the active base, which strictly is defined by the emitter-base junction, and the extrinsic base EB there remains a safety clearance that is minimized in the method according to the invention.

Figure 7 shows a finished bipolar transistor, in which, in comparison with the previous arrangement the contacts for the connection of the individual transistor layers have now also been produced. By way of example, an emitter contact EK is produced directly above the emitter E, said emitter contact being formed from polysilicon or a metal, in particular from aluminum, tungsten or copper. In the region of the extrinsic base EB, above the base layer in the dielectric layer DS and the other layers optionally applied thereabove, in a window, the base layer BS is uncovered and the base contact BK is applied. The contact to the collector is implemented outside the transistor region. For this purpose, a collector connection KA highly doped with dopant of the second conductivity type is produced in the semiconductor

substrate HLS. By means of the collector connection KA, contact is made with a deeply situated, highly doped buried collector layer VK, which is in turn connected to the collector zone KG and a selectively implanted collector zone KA. In this way, a continuously highly doped and thus low-resistance connection is produced via collector connection KA, buried collector layer VK and collector zone KG, which all have a high doping of the second conductivity type.

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The transistor according to the invention is distinguished by an intrinsic base which can be kept relatively thin and the dopant distribution of which is defined by the epitaxial deposition. The small thickness enables rapid bridging of the intrinsic base by the charge carriers initiated by the emitter and thus short switching times of the transistor. Moreover, the intrinsic base is not widened by outdiffusion of its dopant elements, in particular the boron atoms, into adjacent layer regions of emitter or collector, as would be expected as a disadvantageous concomitant phenomenon particularly in the case of the known dopant implantation of the entire base layer. Overall a low-resistance connection of the intrinsic base and thus of the entire transistor is nevertheless made possible via the extrinsic base which has low resistance and thus good electrical conductivity as a result of the indiffusion of additional dopant. By means of the method according to the invention, the individual component parts of the transistor can be sufficiently separated without the resistance of the base terminal thereby being increased in comparison with known transistors. Therefore, a transistor according to the invention is suitable particularly for fast logic and analog circuits and permits a high switching frequency.

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The distance between the highly doped extrinsic base and the emitter can be chosen with the aid of the

method according to the invention such that, on the one hand, a low-resistance base terminal via the extrinsic base toward the emitter/base junction is possible and, on the other hand, the tunneling of charge carriers  
5 between the highly doped region of the base layer and the highly doped emitter is restricted to a desired value or decreased below a maximum value that can be afforded tolerance.

10 Although the method according to the invention has been able to be described only on the basis of a single exemplary embodiment, it is not at all restricted thereto. Rather, numerous modifications of the specified method parameters and in particular of the  
15 material selection lie within the scope of the invention.